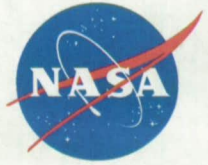


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National Aeronautics and Space Administration



NASA-DoD Lead-Free Electronics Project

2009 Defense Manufacturing Conference

November 30, 2009

Overview

- Testing project will build on the results from the JCAA/JGPP LFS Project
- The primary technical objective of this project is to undertake comprehensive testing to generate information on **failure modes/criteria** to better understand the reliability of:
- Packages (e.g., Thin Small Outline Package [TSOP], Ball Grid Array [BGA], Plastic Dual In-line Package [PDIP]) assembled and reworked with lead-free alloys
- Packages (e.g., TSOP, BGA, PDIP) assembled and reworked with mixed (lead/lead-free) alloys.
- Project documents, test plans, test reports and other associated information will be available on the web:
- NASA-DoD Lead-Free Electronics Project:
http://www.teerm.nasa.gov/projects/NASA_DODLeadFreeElectronics_Proj2.html
- JCAA/JGPP Lead-Free Solder Project
http://www.teerm.nasa.gov/projects/LeadFreeSolderTestingForHighReliability_Proj1.html

Comparison of NASA-DoD LFE Project to predecessor JCAA/JG-PP LFS Project

- **Similarities**

- Virtually identical test vehicle
- Procedures identical for most tests
- Same facility for assembly
- SN100C being used for wave soldering

- **Differences**

- Test articles will be thermally aged after assembly (100°C for 24 hours)
- Increased rework
- Increased solder mixing
- Mechanical shock test procedure
- Drop testing
- Immersion Ag surface finish for most test vehicles (Limited number will have ENIG)
- SAC305 being used for reflow soldering
- SN100C being used for reflow soldering

Project Stakeholders



U.S. AIR FORCE

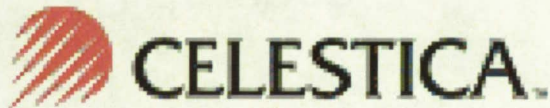


**Rockwell
Collins**

BAE SYSTEMS



your partner for soldering solution

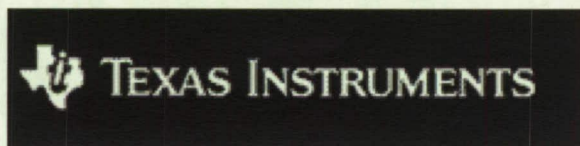


Raytheon

calce™

Honeywell

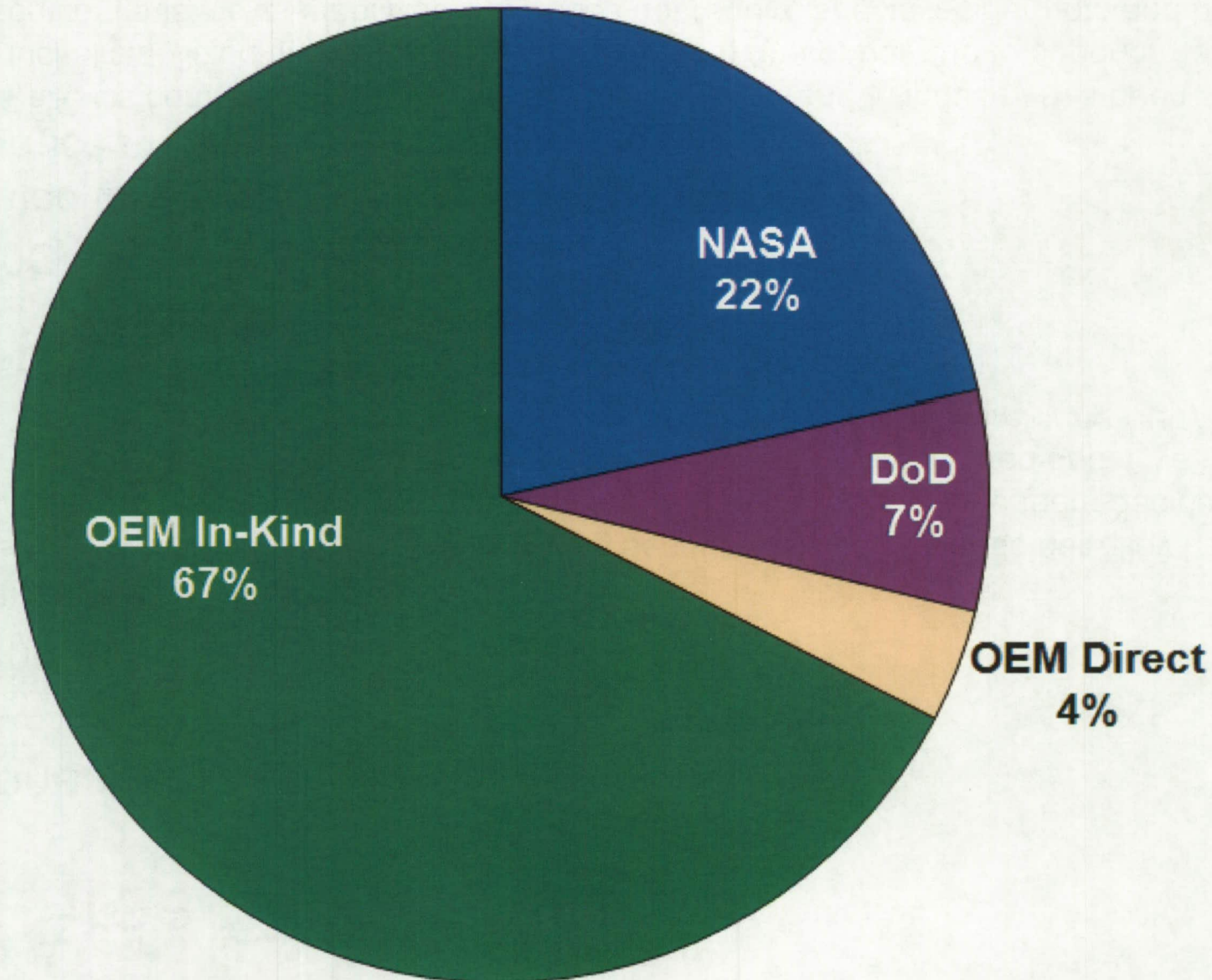
GENERAL DYNAMICS
Advanced Information Systems



HARRIS



Contributions to the NASA-DoD Lead-Free Electronics Project ~\$2 Million



Lead-Free Solder Alloys

Which ones?

- SAC305 (Sn3.0Ag0.5Cu)

- Surface mount assembly

This alloy was chosen for reflow soldering because this particular solder alloy has shown the most promise as a primary replacement for tin-lead solder. The team decided that they wanted to select at least one “general purpose” alloy to be evaluated and it was determined that the SnAgCu solder alloy would best serve this purpose. {EnviroMark™ 907 from Kester.}

- SN100C (Sn0.7Cu0.05Ni+Ge)

- Plated through hole

- Surface mount assembly

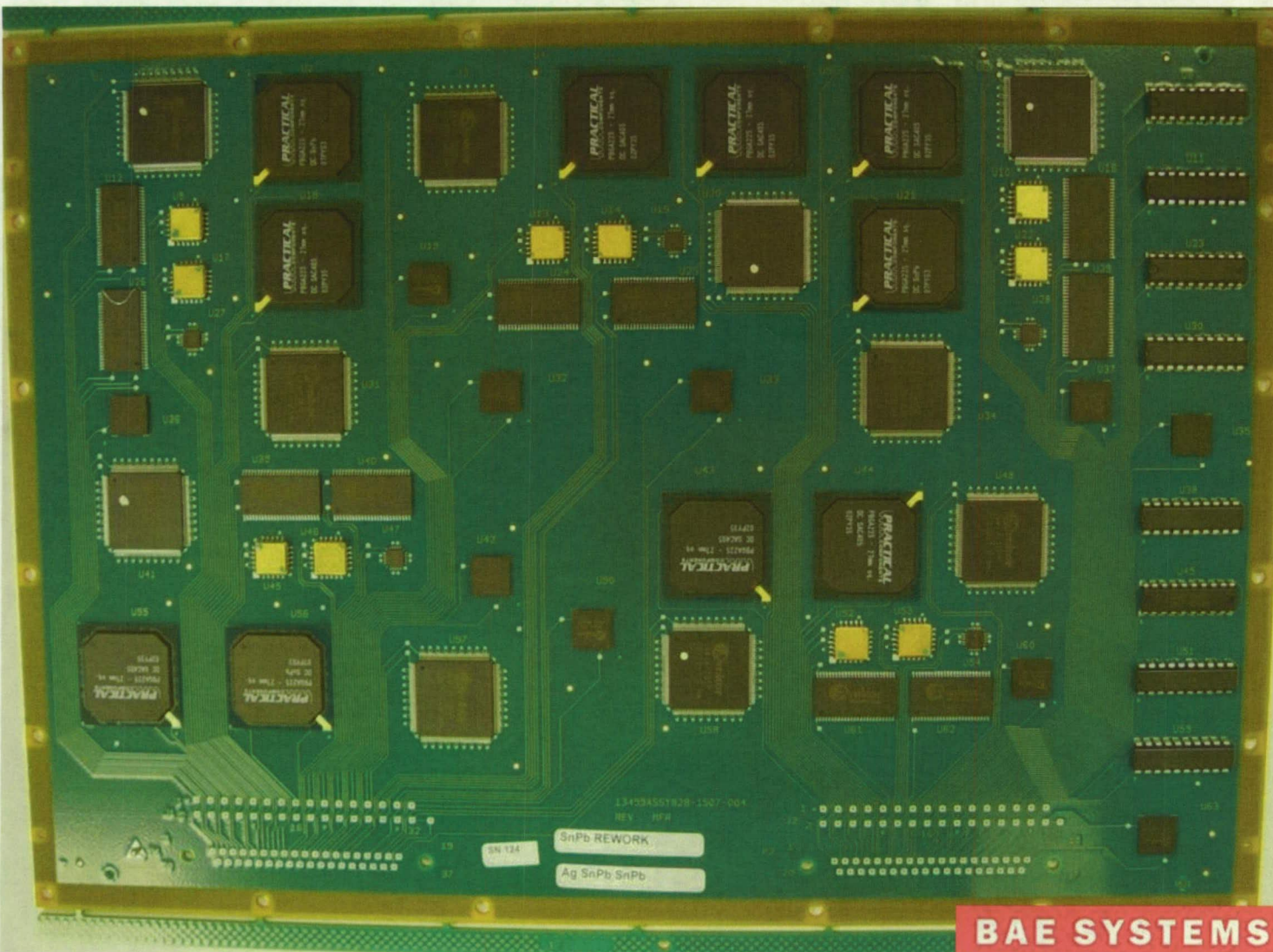
This alloy is commercially available and the general trend in industry has been switching to the nickel stabilized tin-copper alloy over standard tin-copper due to superior performance. In addition, this nickel-stabilized alloy does not require special solder pots and has shown no joint failures in specimens with over 4 years of service.

Test Vehicles

- 193 Test Vehicles Assembled by BAE Systems (Irving, Texas)
120 = “Manufactured”
73 = “Rework”

Circuit Cards

- 14.5”X 9”X 0.09”
- 6 layers of 0.5 ounce copper
- FR4 per IPC-4101/26 with a minimum Tg of 170°C (Isola 370HR)
- Pho-Tronics



Component Finish/Solder Combinations

SnPb Manufactured Test Vehicles				
Component	Component Finish	Reflow Solder	Wave Solder	Board Finish
BGA-225	SAC405	SnPb		Immersion Silver
BGA-225	SnPb	SnPb		
CLCC-20	SAC305	SnPb		
CLCC-20	SnPb	SnPb		
CSP-100	SAC105	SnPb		
CSP-100	SnPb	SnPb		
PDIP-20	NiPdAu		SnPb	
PDIP-20	Sn		SnPb	
QFN	Matte Sn	SnPb		
TQFP-144	Matte Sn	SnPb		
TQFP-144	SnPb Dip	SnPb		
TSOP-50	SnBi	SnPb		
TSOP-50	SnPb	SnPb		

Profiles used during assembly

Reflow Profile = SnPb

Preheat = ~ 120 seconds @140-183°C
 Solder joint peak temperature = 225°C
 Time above reflow = 60-90 sec
 Ramp Rate = 2-3 °C/sec

Wave Profile = SnPb

Solder Pot Temperature = 250°C
 Preheat Board T = 101°C
 Peak Temperature = 144°C
 Speed: 110 cm/min

Component Finish/Solder Combinations

Lead-Free Manufactured Test Vehicles							
Component	Component Finish	Set A			Set B		
		Reflow Solder	Wave Solder	Board Finish	Reflow Solder	Wave Solder	Board Finish
BGA-225	SnPb	SAC305		Immersion Silver ----- A limited Number of Boards will be Built with ENIG	SN100C		Immersion Silver
BGA-225	SAC405	SAC305			SN100C		
CLCC-20	SnPb	SAC305			SN100C		
CLCC-20	SAC305	SAC305			SN100C		
CSP-100	SnPb	SAC305			SN100C		
CSP-100	SAC105	SAC305			SN100C		
PDIP-20	NiPdAu		SN100C			SN100C	
PDIP-20	Sn		SN100C			SN100C	
QFN	Matte Sn	SAC305			SN100C		
TQFP-144	SnPb Dip	SAC305			SN100C		
TQFP-144	Matte Sn	SAC305			SN100C		
TSOP-50	SnPb	SAC305			SN100C		
TSOP-50	SnBi	SAC305			SN100C		

Profiles used during assembly

Reflow Profile = SAC305

Preheat = 60-120 seconds @150-190°C

Peak temperature target = 243°C

Reflow:~20 seconds above 230°C

~30-90 seconds above 220°C

Wave Profile = SN100C

Solder Pot Temperature = 265°C

Preheat Board T = 134°C

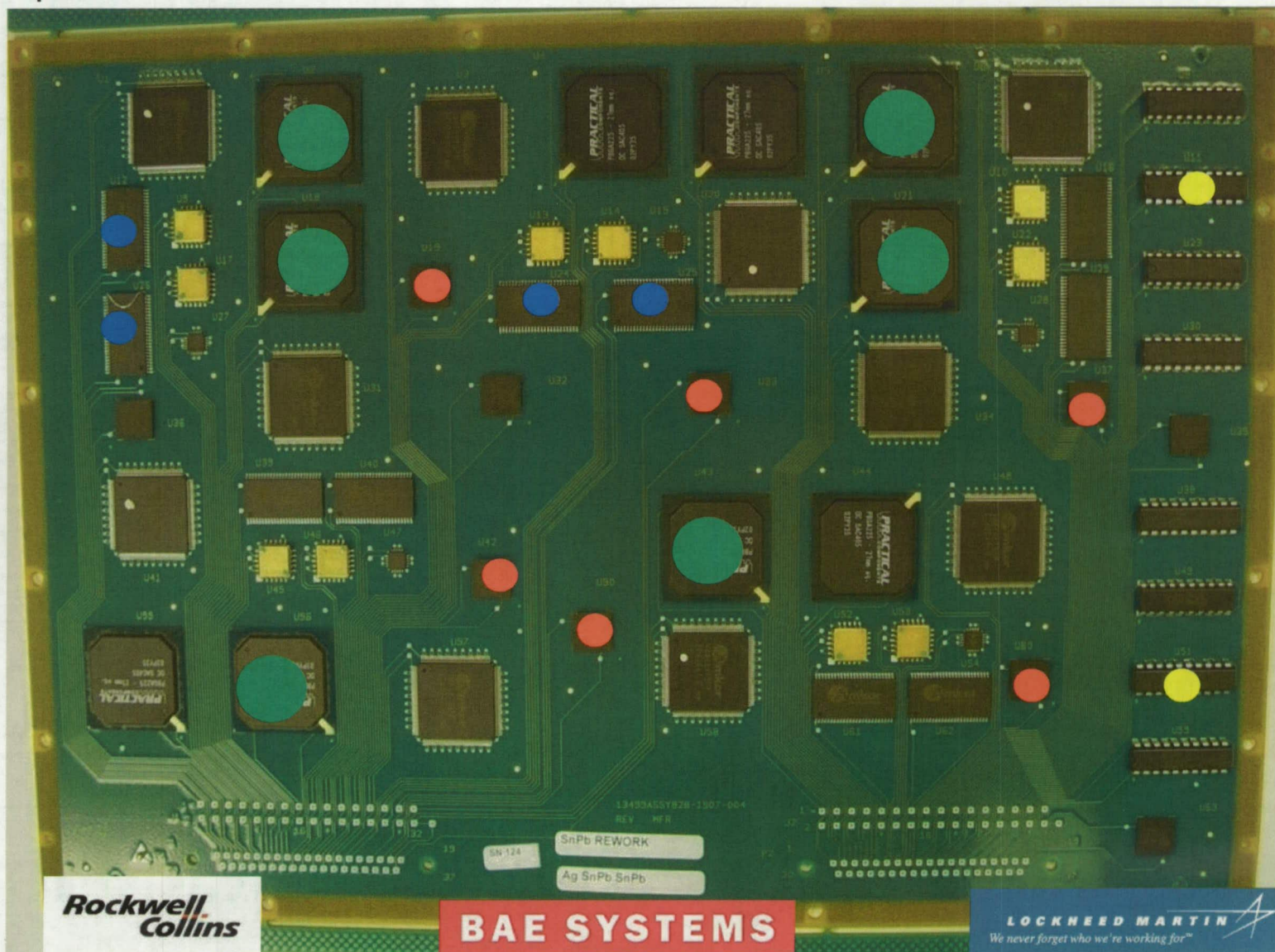
Peak Temperature = 157°C

Speed: 90 cm/min

“Rework” Test Vehicles

- 73 Test vehicles being reworked (sub-set of the 193 assembled)
- 3 Locations completed the rework

RefDes	Component
U18	BGA-225
U43	BGA-225
U06	BGA-225
U02	BGA-225
U21	BGA-225
U56	BGA-225
U33	CSP-100
U50	CSP-100
U19	CSP-100
U37	CSP-100
U42	CSP-100
U60	CSP-100
U11	PDIP-20
U51	PDIP-20
U12	TSOP-50
U25	TSOP-50
U24	TSOP-50
U26	TSOP-50



Component Finish/Solder Combinations

SnPb Rework Test Vehicles						
Component	Original Component Finish	Reflow Solder	Wave Solder	New Component Finish	Rework Solder	Board Finish
BGA-225	SAC405	SnPb				Immersion Silver ----- A limited Number of Boards will be Built with ENIG
BGA-225	SnPb	SnPb		SAC405	SnPb	
BGA-225	SnPb	SnPb		SnPb	Flux Only	
CLCC-20	SAC305	SnPb				
CSP-100	SAC105	SnPb				
CSP-100	SnPb	SnPb		SnPb	Flux Only	
CSP-100	SnPb	SnPb		SAC105	SnPb	
PDIP-20	NiPdAu		SnPb			
PDIP-20	Sn		SnPb			
PDIP-20	SnPb		SnPb	Sn	SnPb	
QFN	Matte Sn	SnPb				
TQFP-144	NiPdAu	SnPb				
TQFP-144	SnPb Dip	SnPb				
TSOP-50	Sn	SnPb				
TSOP-50	SnBi	SnPb				
TSOP-50	SnPb	SnPb		SnPb	SnPb	
TSOP-50	SnPb	SnPb		Sn	SnPb	

Profiles used during initial assembly

LF profiles used

Reflow Profile = SAC305

Preheat = 60-120 seconds @150-190°C

Peak temperature target = 243°C

Reflow:~20 seconds above 230°C

~30-90 seconds above 220°C

Wave Profile = SN100C

Solder Pot Temperature = 265°C

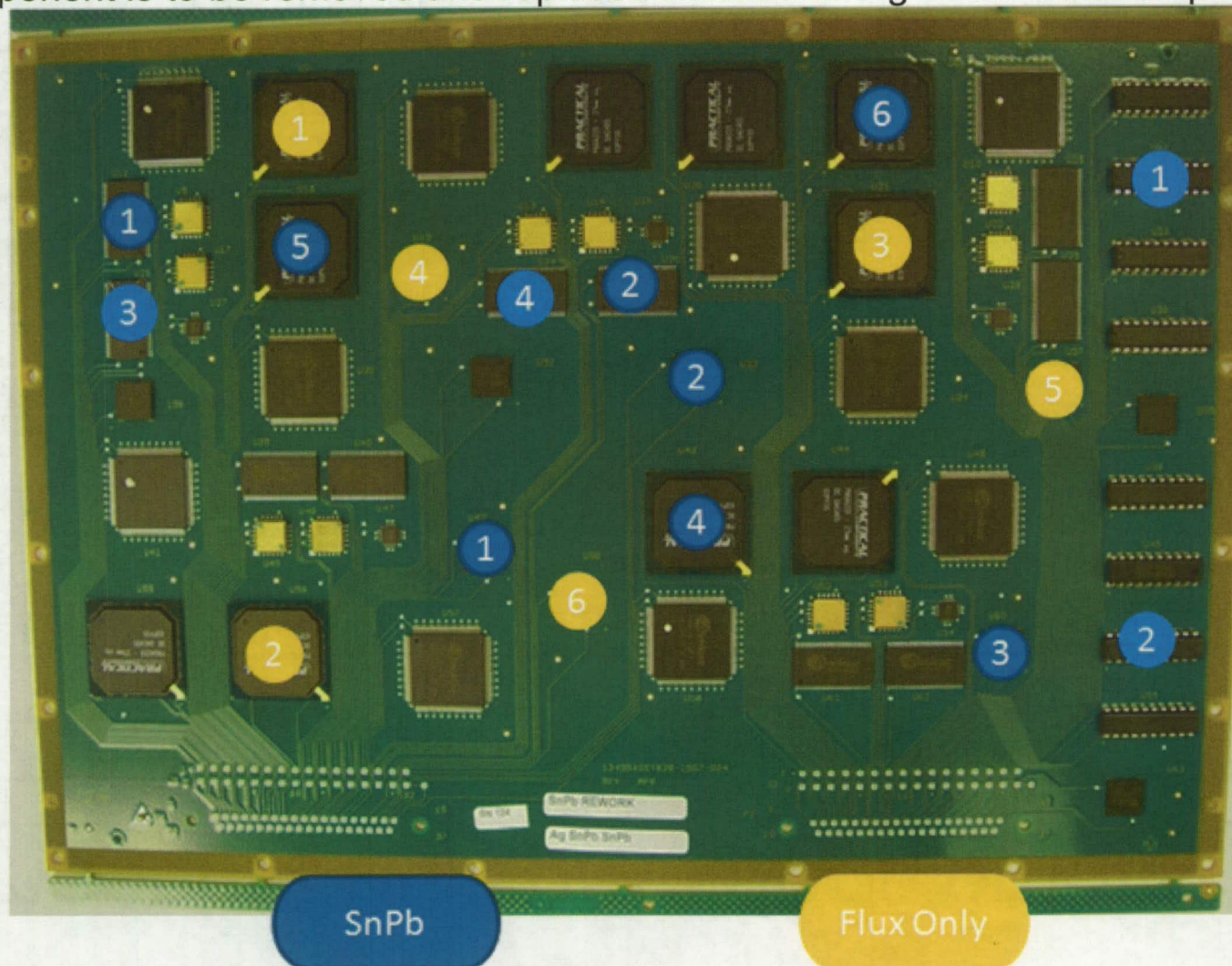
Preheat Board T = 134°C

Peak Temperature = 157°C

Speed: 90 cm/min

Rework Procedure

- Components being reworked have been grouped by rework solder alloy / material (SnPb, Flux only, SAC305 and SN100C). The location performing the rework can choose what order to rework the solder alloy / material groups, but must use the numbered order below for specific component locations within the solder alloy / material group. When reworking a component, the component is to be removed and replaced before moving to the next component.



Component Finish/Solder Combinations

Lead-Free Rework Test Vehicles						
Component	Component Finish	Reflow Solder	Wave Solder	New Component Finish	Rework Solder	Board Finish
BGA-225	SnPb	SAC305				Immersion Silver
BGA-225	SAC405	SAC305		SAC405	SnPb	
BGA-225	SAC405	SAC305		SAC405	Flux Only	
CLCC-20	SnPb	SAC305				
CSP-100	SnPb	SAC305				
CSP-100	SAC405	SAC305				
CSP-100	SAC105	SAC305		SAC105	Flux Only	
CSP-100	SAC105	SAC305		SAC105	SnPb	
PDIP-20	Sn		SN100C			
PDIP-20	Sn		SN100C	Sn	SN100C	
QFN	SnPb	SAC305				
TQFP-144	NiPdAu	SAC305				
TQFP-144	SAC 305 Dip	SAC305				
TSOP-50	SnBi	SAC305				
TSOP-50	SnPb	SAC305				
TSOP-50	Sn	SAC305		Sn	SnPb	
TSOP-50	SnBi	SAC305		SnBi	SAC305	

Profiles used during initial assembly

Reflow Profile = SAC305

Preheat = 60-120 seconds @150-190°C

Peak temperature target = 243°C

Reflow:~20 seconds above 230°C

~30-90 seconds above 220°C

Wave Profile = SN100C

Solder Pot Temperature = 265°C

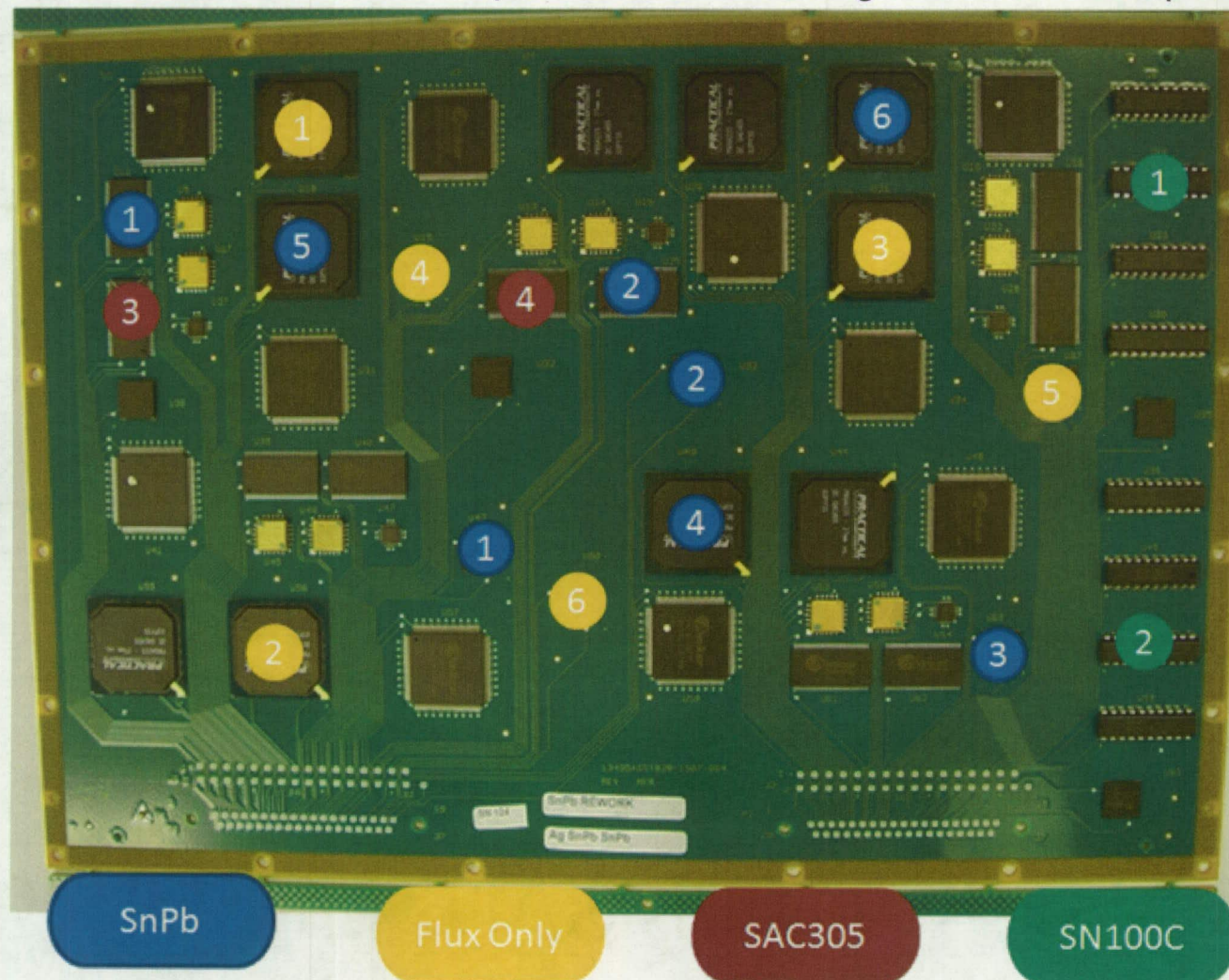
Preheat Board T = 134°C

Peak Temperature = 157°C

Speed: 90 cm/min

Rework Procedure


- Components being reworked have been grouped by rework solder alloy / material (SnPb, Flux only, SAC305 and SN100C). The location performing the rework can choose what order to rework the solder alloy / material groups, but must use the numbered order below for specific component locations within the solder alloy / material group. When reworking a component, the component is to be removed and replaced before moving to the next component.



NAVSEA Crane Rework Effort

- Built 30 test vehicles (sub-set of the 193 assembled)
 - Test vehicles were built with **Lead-Free solder and Lead-Free component finishes only** = similar to Manufactured test vehicles for Mechanical Shock, Vibration and Drop Testing
 - Lead-Free alloys, SAC305 and SN100C
 - Rework was done using **only SnPb solder**
 - Performed multiple pass rework 1 to 2 times on random Pb-free DIP, TQFP-144, TSOP-50, LCC and QFN components
 - Testing
 - Thermal Cycling -55°C to +125°C – Testing In-Progress with NASA-DoD test vehicles
 - Vibration Testing - **TESTING COMPLETE**
 - Drop Testing - **TESTING COMPLETE**

**Rockwell
Collins**




 **CELESTICA.**

Testing Activities

NASA-DoD Test Vehicles

Specific testing details can be found in the Joint Test Protocol (JTP)

http://www.teerm.nasa.gov/projects/NASA_DODLeadFreeElectronics_Proj2.html

- Thermal Cycle Testing (-20/+80°C) 
- Combine Environments Testing **Raytheon**
- Drop Testing  CELESTICA.
- Thermal Cycle Testing (-55/+125°C) **Rockwell Collins**
- Vibration Testing 
- Mechanical Shock Testing 
- Interconnect Stress Test (IST) 
- Copper Dissolution  CELESTICA. **Rockwell Collins**

Thermal Cycle Testing (-20/+80°C)

Test Parameters

- 5 to 10°C/minute ramp
- 30 minute dwell at 80°C
- 10 minute dwell at -20°C

Test vehicles

- Mfg. SnPb = 5
- Mfg. LF = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Testing started - July 5, 2009
~ 1200 Thermal Cycles Completed



Phase 1 = JCAA/JGPP Lead Free Solder Project - Thermal Cycle Testing (-20/+80°C)

27,135 Thermal Cycles Completed

Under the conditions of this test, Sn3.9Ag0.6Cu (SAC) and Sn3.4Ag1.0Cu3.3Bi (SACB) were always more reliable than eutectic SnPb regardless of component type (CLCC, TSOP, BGA or TQFP).



Combine Environments Testing

TESTING COMPLETE

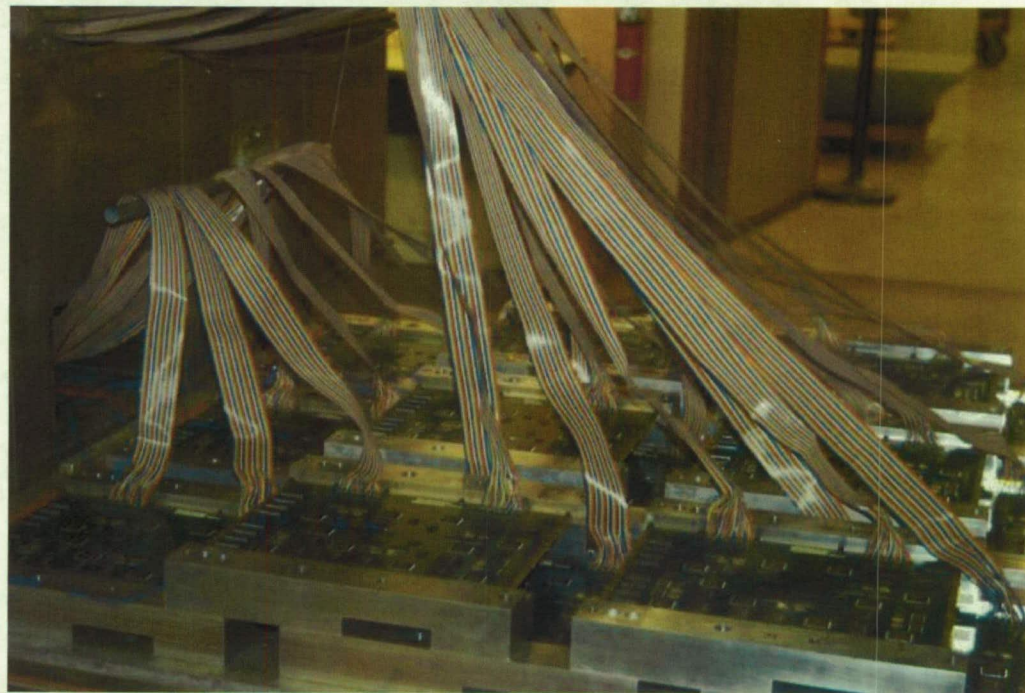
Thermal Cycle with Vibration

- -55°C to +125°C
- 20°C/minute ramp
- 15 minute dwell at -55°C and +125°C
- Vibration for the duration of the thermal cycle
- 10 g_{rms} pseudo-random vibration initially
- Increase vibration level 5 g_{rms} after every 50 cycles
- 55 g_{rms} maximum



Test vehicles

- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Mfg. LF (ENIG) = 1
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

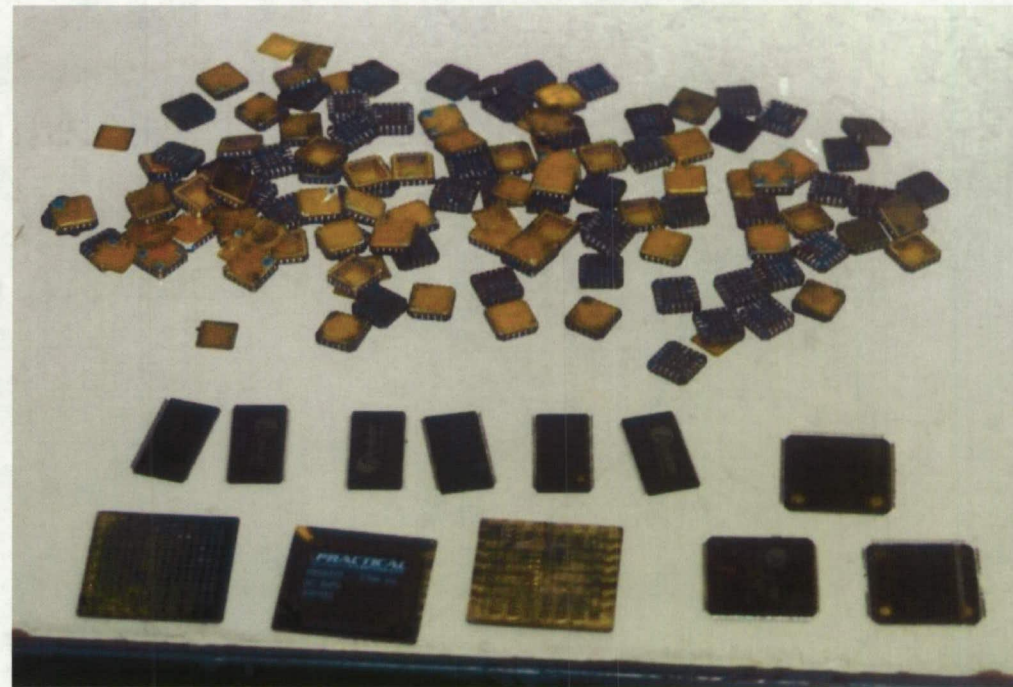


Raytheon

Combine Environments Testing - Status

“Manufactured” Test Vehicles

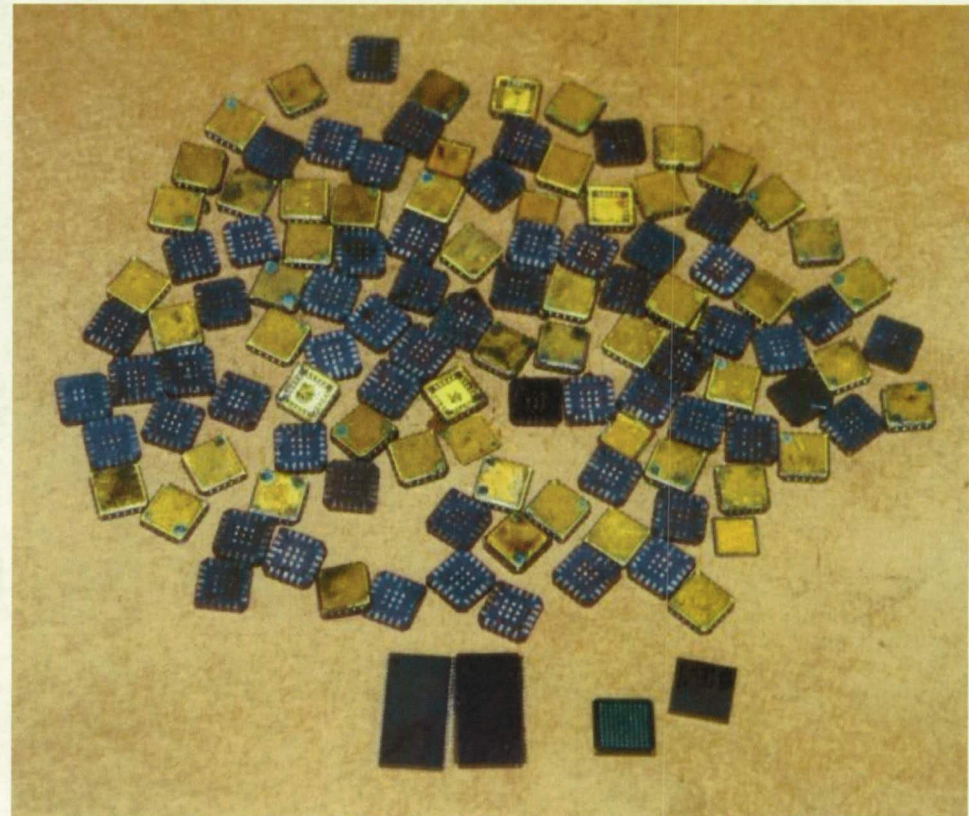
- 650 cycles completed on April 1, 2009
- Data Analysis In Progress
 - BGA's failed = 81%
 - CLCC's failed = 93%
 - CSP's failed = 38%
 - Sn PDIP's failed = 5%
 - NiPdAu PDIP's failed = 3%
 - QFN's failed = 27%
 - TQFP's failed = 29%
 - TSOP's failed = 24%



Combine Environments Testing - Status

“Rework” Test Vehicles

- 650 cycles completed on June 14, 2009
- Data Analysis In Progress
 - BGA's failed = 52%
 - CLCC's failed = 96%
 - CSP's failed = 28%
 - Sn PDIP's failed = 11%
 - NiPdAu PDIP's failed = 1%
 - QFN's failed = 22%
 - TQFP's failed = 15%
 - TSOP's failed = 48%



Drop Testing

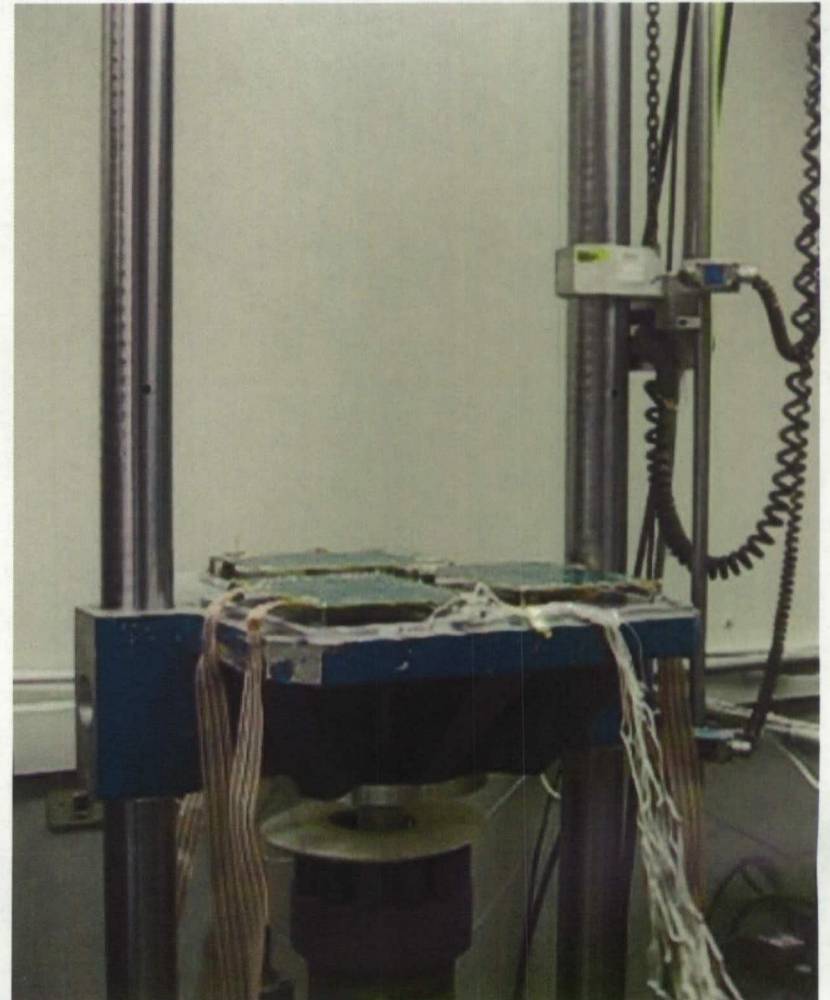
TESTING COMPLETE

NASA-DoD Test Vehicles

- Shock testing will be conducted in the Z - axis
- 500Gpk input, 2ms pulse duration
- Test vehicles will be dropped until all monitored components fail or 10 drops have been completed

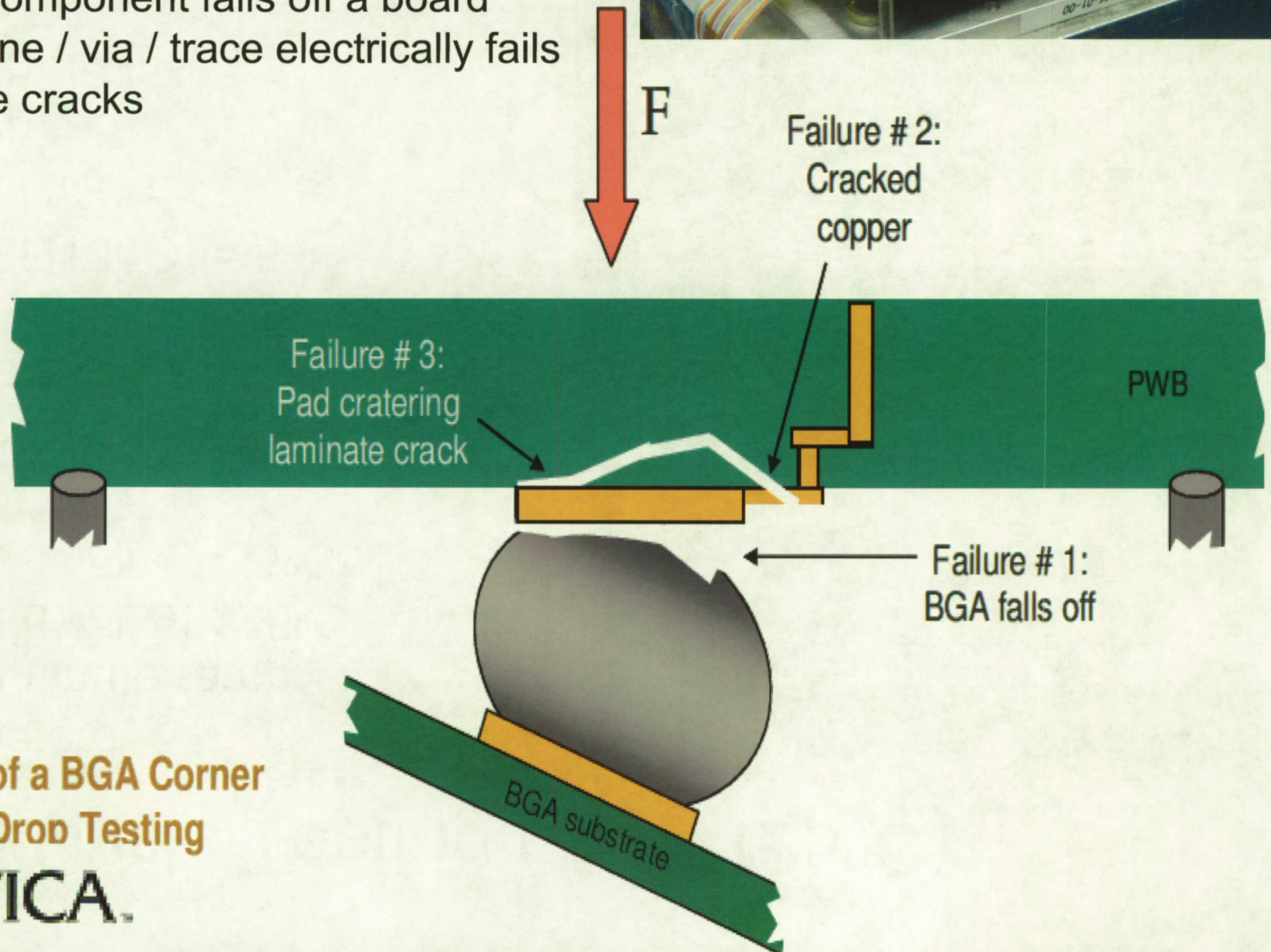
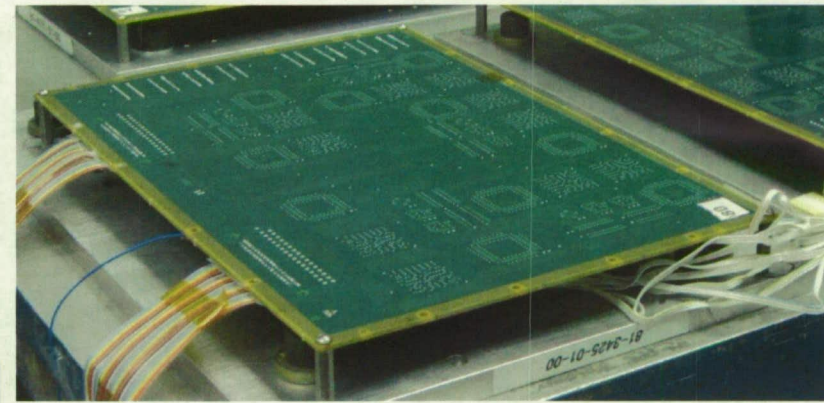
Test vehicles

- Mfg. SnPb = 5
- Mfg. LF = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5



Drop Testing

1. A BGA ball/component falls off a board
2. A Cu dog bone / via / trace electrically fails
3. The laminate cracks



Schematic of a BGA Corner
Joint After Drop Testing



CELESTICA

Thermal Cycle Testing (-55/+125°C)

Test Parameters

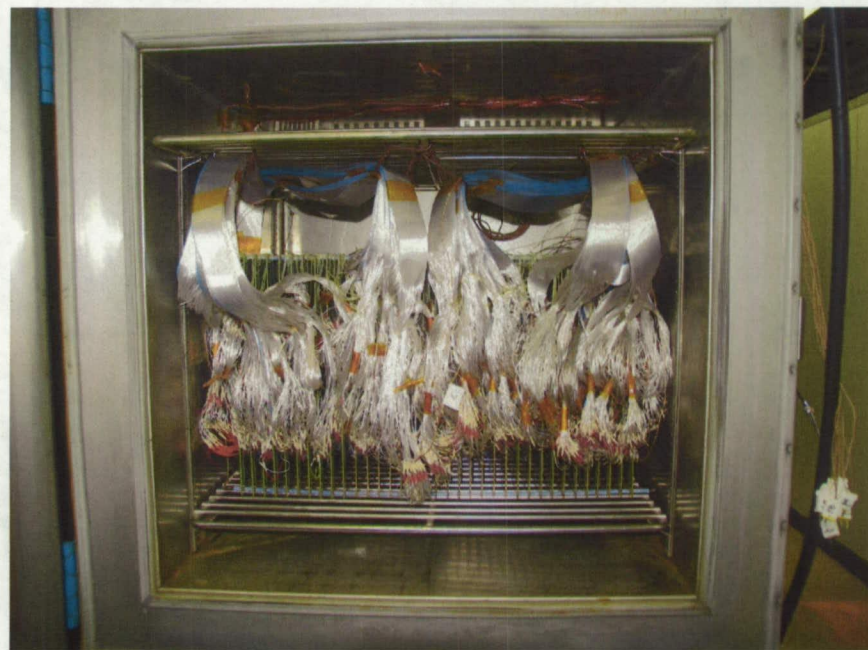
- 5 to 10°C/minute ramp
- 30 minute dwell at 125°C
- 10 minute dwell at -55°C

Test vehicles

- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Mfg. LF (ENIG) = 1
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

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Collins**

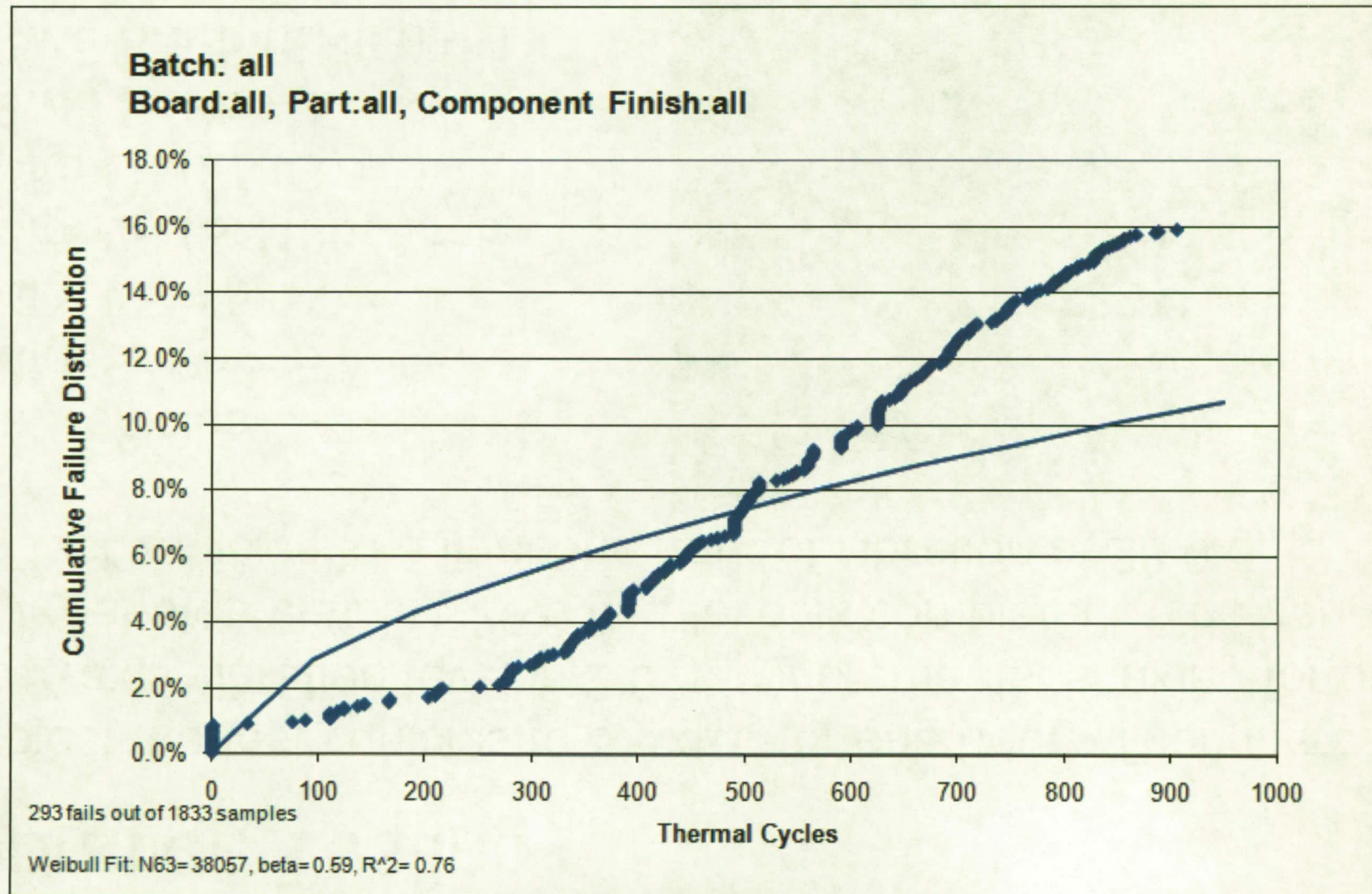
Testing started - July 17, 2009
~900 Thermal Cycles Completed



Thermal Cycle Testing (-55/+125°C)

Data Snapshot from “Manufactured” Test Vehicles

- No “Rework” Data



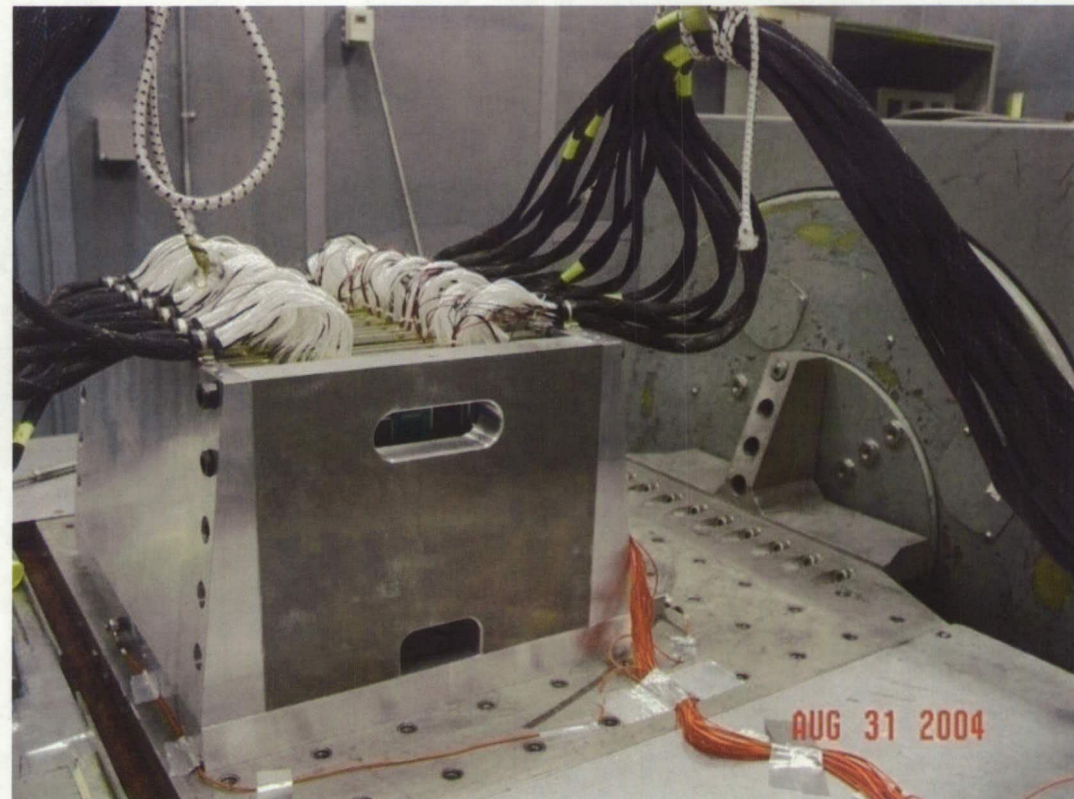
Vibration Testing

Subject the test vehicles to $8.0 \text{ g}_{\text{rms}}$ for one hour. Then increase the Z-axis vibration level in $2.0 \text{ g}_{\text{rms}}$ increments, shaking for one hour per step until the $20.0 \text{ g}_{\text{rms}}$ level is completed. Then subject the test vehicles to a final one hour of vibration at $28.0 \text{ g}_{\text{rms}}$.

Test vehicles

- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Mfg. LF (ENIG) = 1
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Testing Started – July 8, 2009



Mechanical Shock Testing

TESTING COMPLETE

Project representatives felt that only testing in the Z-axis was required as this is the only axis which allows significant board bending and subsequent solder joint failures.

Testing complete

Test vehicles

- Mfg. SnPb = 5
- Mfg. LF = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

Parameters	The shock transients will be applied perpendicular to the plane of the board and will be increased after every 100 shocks (i.e., a step stress test). For Level 6 (300 G's), 400 shocks will be applied. Frequency range is 40 to 1000 Hz. SRS damping: 5%			
	Test Shock Response Spectra	Amplitude (G's)	Te (msec)	Shocks per Level
	Modified Functional Test for Flight Equipment (Level 1)	20	<30	100
	Modified Functional Test for Ground Equipment (Level 2)	40	<30	100
	Modified Crash Hazard Test for Ground Equipment (Level 3)	75	<30	100
	Level 4	100	<30	100
	Level 5	200	<30	100
	Level 6	300	<30	400
Number of Test Vehicles Required				
Manufactured		Rework		
Mfg. SnPb	Mfg. LF	Rwk. SnPb	Rwk. SnPb ENIG	Rwk. LF
5	5	5	1	5
Trials per Specimen		1		



Mechanical Shock Testing

Component	% of Components Failed During Mechanical Shock Testing			
	"Manufactured" Test Vehicles		"Rework" Test Vehicles	
	SnPb	Pb-Free	SnPb	Pb-Free
BGA-225	94	96	95	100
CLCC-20	22	30	22	30
CSP-100	32	26	42	38
PDIP-20	53	73	54	58
QFN-20	0	10	0	0
TQFP-144	70	62	68	80
TSOP-50	4	0	22	20




Copper Dissolution

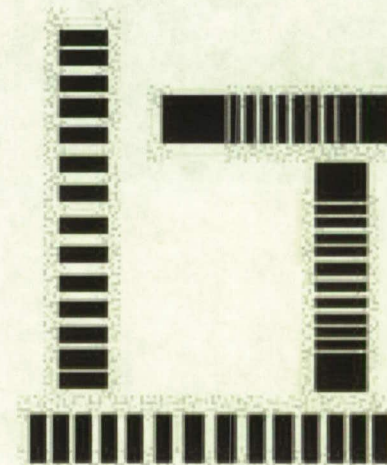
- Printed Circuit Board (PCB) land and plated through-holes can be eroded or dissolved away in the presence of molten solder rendering the PCB non-functional. Significant dissolution can occur with the use of **certain new Sn-rich alloys** and is further exacerbated by higher process temperatures.
- Mini-wave soldering versus manual soldering
- Number of component removals: 1X versus 3X
- PDIPS on break off coupon and QFP pad pattern
- Metallographic Analysis:
 - As fabricated copper thickness
 - As assembled copper thickness
- As reworked copper thickness

Test coupons

- Mfg. SnPb = 5
- Mfg. LF = 5
- Mfg. LF (SN100C) = 5
- Rwk. SnPb = 5
- Rwk. SnPb (ENIG) = 1
- Rwk. LF = 5

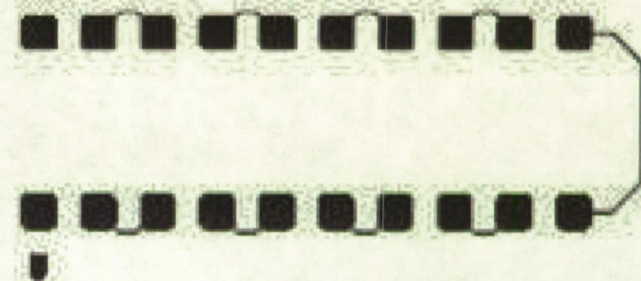
**Rockwell
Collins**

 **CELESTICA**



SMT Copper
Dissolution Pattern

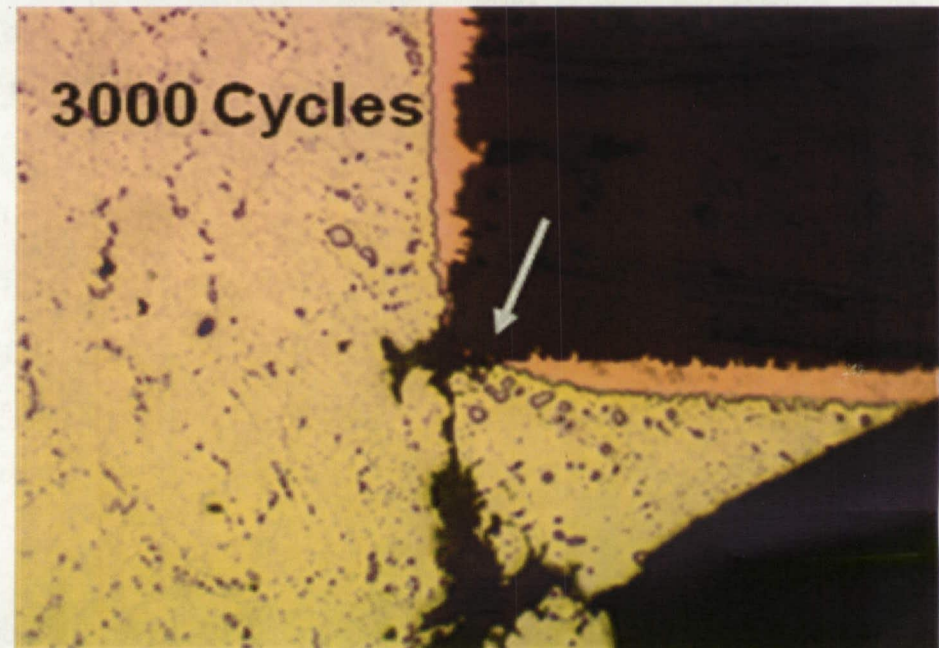
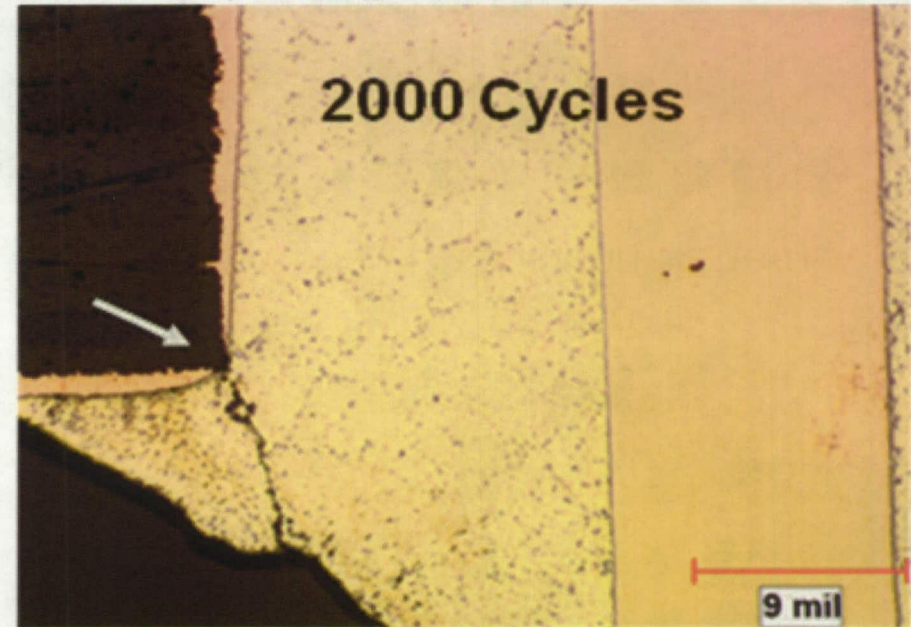
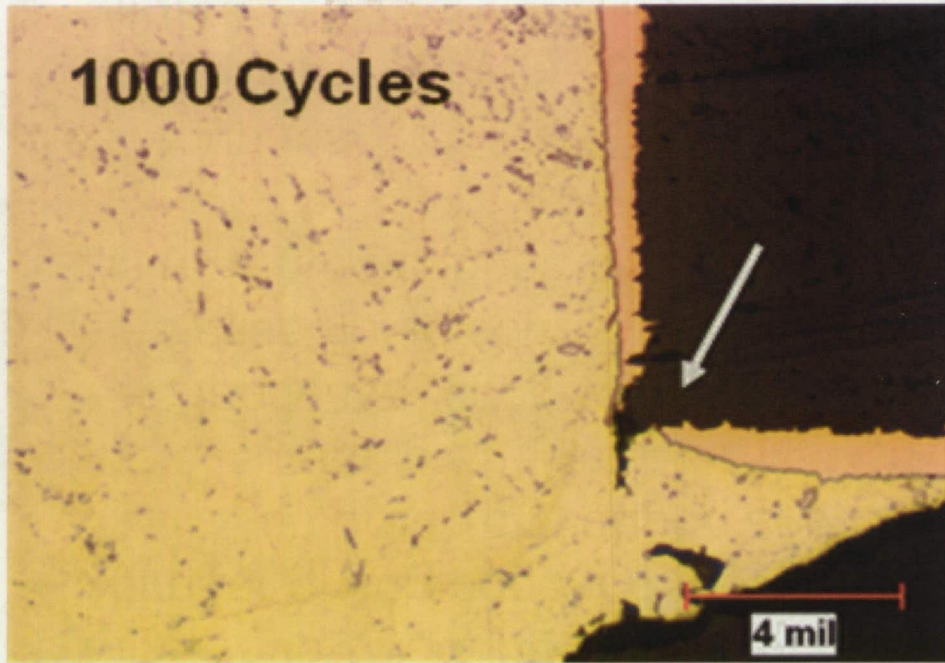
U64




Plated Through-Hole Copper
Dissolution Pattern

Copper Dissolution

Cracks generated from the lack of Cu knee (SAC405 solder) during Thermal Cycle Testing {0°C to 100°C}



The Cu layer was dissolved completely or partially in the knee regions of SAC405 PTH joints during rework. The cracks start growing from non-Cu knee regions after 1000cycles. The direction of the cracks was close to 45° to the knee.

A photograph of a space shuttle launching, with a large plume of fire and smoke. In the foreground, a tall water tower is visible against a dark sky.

Kurt Kessel

ITB, Inc.

NASA Technology Evaluation for Environmental Risk
Mitigation Principal Center (TEERM)

Kennedy Space Center, FL

Phone: 321-867-8480

E-Mail: kurt.r.kessel@nasa.gov

Website: www.teerm.nasa.gov

NASA-DoD Lead-Free Electronics Project:

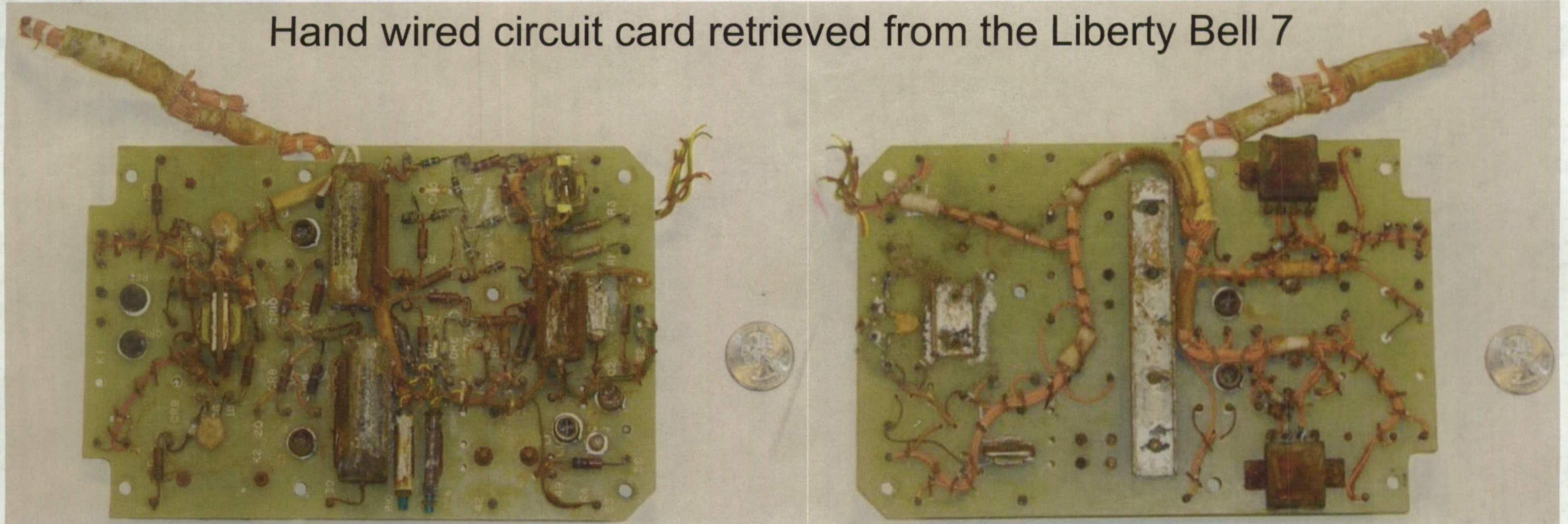
http://www.teerm.nasa.gov/projects/NASA_DODLeadFreeElectronics_Proj2.html

JCAA/JGPP Lead-Free Solder Project

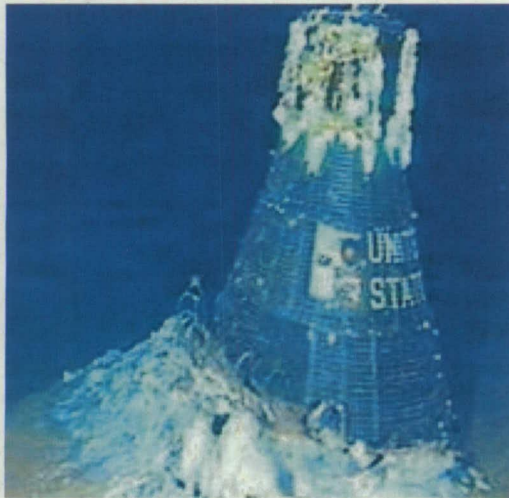
http://www.teerm.nasa.gov/projects/LeadFreeSolderTestingForHighReliability_Proj1.html

Questions

Hand wired circuit card retrieved from the Liberty Bell 7

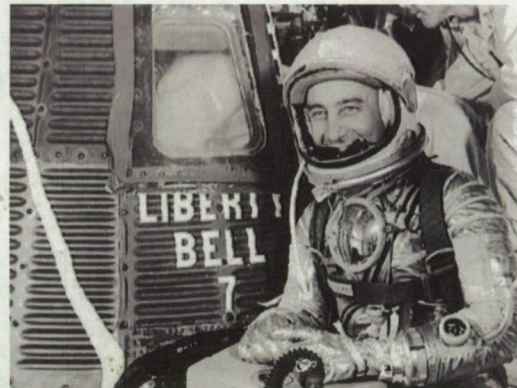


(<http://apollotribute.blogspot.com/2005/11/liberty-bell-7-circuit-card.html>)



On July 21, 1961 a Mercury/Redstone rocket carried Grissom on a 15-minute trip through space, successfully repeating the feat performed by Alan Shepard two months earlier.

The Liberty Bell 7 was pulled from a depth of 15,000 feet -- 3,000 feet deeper than the Titanic on July 20, 1999



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14. ABSTRACT <p>In response to concerns about risks from lead-free induced faults to high reliability products, NASA has initiated a multi-year project to provide manufacturers and users with data to clarify the risks of lead-free materials in their products. The project will also be of interest to component manufacturers supplying to high reliability markets.</p> <p>The project was launched in November 2006. The primary technical objective of the project is to undertake comprehensive testing to generate information on failure modes/criteria to better understand the reliability of:</p> <ul style="list-style-type: none"> - Packages (e.g., TSOP, BGA, PDIP) assembled and reworked with solder interconnects consisting of lead-free alloys - Packages (e.g., TSOP, BGA, PDIP) assembled and reworked with solder interconnects consisting of mixed alloys, lead component finish/lead-free solder and lead-free component finish/SnPb solder 						
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